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Research Article

Differences between laboratory and sensor analyses for soil attributes[1]

Gabriel Benhossi[2], Étore Francisco Reynaldo[3], Thiago Martins Machado[4]

ABSTRACT

Sensors used in precision agriculture can perform readings of georeferenced points aiming to determine the electrical conductivity, pH and organic matter. These devices have a high operational capacity, but with little information on the quality of their collected data. This study aimed to establish correlations and differences among electrical conductivity, pH and organic matter data collected by sensor and obtained by laboratory analyses. The results were analyzed by statistical correlations, geostatistical analyses and map generation by the kriging interpolation method of electrical conductivity, pH and organic matter, using dedicated softwares. The sensor showed that the data collected for electrical conductivity, pH and organic matter are reliable and robust, due to the high spatial dependence and correct sampling distance confirmed by the range values.

KEYWORDS: Precision agriculture sensors, soil electrical conductivity, soil attributes.

RESUMO

Diferenças entre análises laboratoriais e por sensor para atributos do solo

Os sensores utilizados na área de agricultura de precisão são capazes de realizar leituras pontuais georreferenciadas, determinando a condutividade elétrica, pH e matéria orgânica, sendo equipamentos de alta capacidade operacional, mas ainda com poucas informações sobre a qualidade dos dados coletados. Objetivou-se estabelecer correlações e diferenças entre dados de condutividade elétrica, pH e matéria orgânica coletados por sensor e obtidos por meio de análises laboratoriais. Os resultados foram analisados por meio de correlações estatísticas, análises geoestatísticas e geração de mapas pelo método de interpolação por krigagem de condutividade elétrica, pH e matéria orgânica, utilizando-se programas dedicados. O sensor demostrou que os dados coletados de condutividade elétrica, pH e matéria orgânica são confiáveis e robustos, devido à alta dependência espacial e à correta distância de amostragem comprovadas pelos valores de alcance.

PALAVRAS-CHAVE: Sensores de agricultura de precisão, condutividade elétrica do solo, atributos do solo.

INTRODUCTION

Organic matter, pH and particle size are among the most important soil attributes, as they directly affect crop yield. Therefore, knowing their spatial variability is essential. According to Souza et al. (2010), detailed knowledge of the spatial variability of fertility attributes may optimize the site-specific application of correctives and fertilizers, thus improving the control of the crop production system.

The soil organic matter plays a fundamental role in the sustainability of agricultural systems, influencing the soil physical, chemical and biological attributes, reflecting on the stability and yield of agroecosystems (Costa et al. 2013). According to Malavolta (2006), knowing the soil pH conditions is essential, as too high or too low pH values imply unfavorable conditions to the plant development.

Particle size analysis is indispensable for agriculture, consisting in determining the proportion of sand, silt and clay particles. Clay directly influences the soil fertility, as it retains negative charges, influencing the soil cation exchange capacity (Malavolta 2006). However, soil sampling would make the operation unfeasible in most cases, since a high number of collection points per hectare is necessary to have a better understanding of the spatial variability. Thus, sensors to determine the soil electrical conductivity and other soil attributes, such as pH and dry matter, appear in this context.

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[2] Solinftec, Sinop, MT, Brasil. *E-mail/ORCID*: gabriel.benhossi@solinftec.com.br/0000-0001-7393-6561.

[3] Syngenta, Uberlândia, MG, Brasil. *E-mai/ORCID*: etore.reynaldo@syngenta.com/0000-0002-2184-7177.

[4] Universidade Federal de Mato Grosso, Instituto de Ciências Agrárias e Ambientais, Sinop, MT, Brasil. *E-mail/ORCID*: tmmachado@ufmt.br/0000-0002-6796-3683.

Serrano et al. (2010) demonstrated the potential of these sensors to measure electrical conductivity and survey some soil characteristics related to fertility and estimate yield, obtaining significant correlations among electrical conductivity, dry matter, pH and altitude.

The use of this type of sensor to measure the soil electrical conductivity and its relationship with soil chemical attributes demonstrated excellent results, according to evaluations carried out by Corassa et al. (2016) in two areas, one with a lower soil chemical quality and another with a higher quality. The apparent electrical conductivity in the lower-chemical quality area showed a positive relationship with Ca, Mg, pH, sum of bases and cation exchange capacity, and a negative relationship with Al and Al saturation. On the other hand, the apparent electrical conductivity in the higher-chemical quality area had a positive relationship with Ca, Mg, soil organic matter and clay content.

Thus, this study aimed to compare data on electrical conductivity, pH and organic matter collected by sensors and sampled and analyzed at laboratories, verifying the difference among them in two different plots.

Figure 1. Municipality of Candói, in the south-central region of the Paraná state, Brazil.

MATERIAL AND METHODS

The soil electrical conductivity data were collected in two areas, both located in Candói (Figure 1), in the south-central region of the Paraná state, Brazil, one of 148.4 ha (25º56′51″S and 51º28′47″W) (area C6) and another of 111.6 ha (25º34′43″S and 52º03′10″W) (area B3) (Figure 2), with a distance of 500 m between them. The soils in the experimental areas are classified as a cambic aluminic Brown Latosol (Embrapa 2013), with a prominent A horizon and particle size class ranging from clayey to very clayey. The areas have been managed under no-tillage for more than 15 years and grown with wheat, oat or barley in the winter and soybean or corn in the summer, under a crop rotation system. The average altitude at the site is 930 m. The regional climate is classified as humid mesothermal subtropical, according to the Köppen-Geiger climate classification, with average maximum temperatures of 28 ºC and average minimum temperatures of 14 ºC. The average annual precipitation is 1,801.5 mm, with well-distributed rainfall throughout the year.

The data collection using sensors was carried out in February 2016. The equipment used to obtain the electrical conductivity data from the soil consisted of a Veris PMC sensor with 1Hz data collection frequency, synchronized with the updates of a Trimble CFX 750 GPS receiver. The equipment was embedded to a John Deere 7195 J tractor operated at the speed of 8 km h^{-1}, with parallel passes of 20 m of distance from each other. A total of 13,648; 13,407; and 1,584 data of electrical conductivity, organic

Figure 2. Shape of the experimental areas B3 (A) and C6 (B).

matter and pH were respectively collected from the C6 plot, as well as 11,314; 11,174; and 1,274 from the B3 plot. The Veris equipment displays an electrochemical sensor that performs pH readings in the soil at a depth of 0.15 m.

This sensor system consists of a soil display that collects samples intermittently, and each sample separately comes into direct contact with two pH electrodes. The sample is then dispensed, and the electrodes are sprayed with water for cleaning, restarting the process (Molin et al. 2015). The equipment can estimate the organic material, and its principle of operation is the use of reflectance to measure the soil organic matter content in real-time at a depth of 0.05 m. The sensor can withstand all environmental conditions commonly found under field operations because of its robustness (Chig et al. 2015).

For pH, organic matter content and particle size laboratory analyses, the soil was sampled in a grid of points, from which one composite sample (3 subsamples) was collected every two hectares, totaling 74 for the C6 plot and 55 for the B3 plot. The depth of the organic matter samples was 0.05 m, while, for the pH and particle size, they were 0.15 m. The pH, organic matter and particle size analyses were performed by five laboratories (UFRGS, FABC, Tecsolo, Coodetec and IAC), considering the mean values. The samplings were performed in the same month as the sensor data collection. All five laboratories used methods proposed by Embrapa (1997) and IAC (2009) for soil chemical and physical analyses. The most detailed method for pH was 0.01 mol L^{-1} of $CaCl_2$ (1:2.5) for IAC, FABC, Tecsolo and Coodetec, and H_2O for UFRGS. The organic matter was evaluated by determining the oxidizable C by $Cr_2O_7^{2-}$, using a colorimetric determination for IAC, UFRGS and FABC, while, for Tecsolo and Coodetec, the Walkley-Black method was used. Finally, the soil particle size was evaluated by the pipette method for ICA, FABC, Tecsolo and Coodetec, and by the densimeter method for UFRGS.

The data interpolation for generating the pH, organic matter and electrical conductivity maps was performed by the kriging method, using the SMS software (AG Leader Technology™).

The descriptive statistical and geostatistical analyses among the data of soil electrical conductivity, pH and organic matter were performed using the GS+ software (Geostatistics for the Environmental Sciences, version 7). Geostatistics is the main tool used to characterize the spatial variability and estimate soil attributes (Marques Júnior et al. 2008).

Theoretical mathematical models, such as spherical, exponential, linear and Gaussian, were tested to adjust the semivariogram scaled by the data variance, defining the parameters nugget effect (C0), sill (C1 + C0), structural component (C1), degree of spatial dependence and range (a). The model chosen to adjust each semivariogram presented the highest correlation coefficient of cross-validation.

The soil properties were analyzed by the Pearson's correlation, using the SSToolbox software, with all the data from the Veris sensor and from the laboratories. After the analysis, due to the low correlations by the sampling grid in points (laboratory), the area was classified into 5 zones: very low, low, medium, high and very high, in decreasing order of soil electrical conductivity values. To this end, the SMS software (AG Leader Technology™) was used. These zones were set based on studies by Castro (2004) and Carvalho (1998), wherein an average of each zone was made and correlated with the Veris sensor total values.

Subsequently, correlation graphs were constructed, and the coefficients of determination were calculated between the electrical conductivity read by the sensor and the variables clay, silt and sand. Correlations were also calculated between the pH and organic matter values read by the sensor and the pH and organic matter values found in the laboratory analysis.

The soil samples were taken in the same day as the electrical conductivity data collection to evaluate the gravimetric water content, which was determined by the standard oven method, with drying at 105 ºC, for 24 hours.

The differences of values among the analyses performed by the five laboratories were quantified by the coefficient of variation (statistical measure of data dispersion).

RESULTS AND DISCUSSION

Both areas presented adequate water content values for the reading using the Veris equipment, as it does not present a good reading performance in very dry soils (Faulin 2005). The average values found for water content were 0.269 kg kg^{-1} (area B3) and 0.291 kg kg^{-1} (area C6).

Table 1 shows the results of the geostatistical analysis for the electrical conductivity, organic matter and pH data collected by the Veris sensor.

All the soil physicochemical characteristics (Table 1) showed high coefficients of determination, except for the organic matter in the area C6. The values for degree of spatial dependence of the analyzed attributes showed a high spatial dependence, as proposed by Zimback (2001), in which the ratio between the structural component and sill should be between 0.75 and 1.00.

In the area B3, the soil electrical conductivity and pH showed a low spatial variability, and that is why their range of values were high, showing that the sampling distance was adequate.

The electrical conductivity presented the highest spatial variability in the area C6 (Table 1), as shown by the smallest range, when compared to the area B3, which is related to the high particle size variability in the area (Table 2).

The semivariogram values (Table 1) showed that the soil attributes had a good resolution, frequency and amount of collected data, in which the collection spacing using the equipment was 20 m, and the shortest range was 68.98 m for organic matter.

Table 2 presents the results of electrical conductivity, clay, silt, sand, pH and organic matter contents for the five zones of electrical conductivity (very low, low, medium, high and very high) which were used to build the representative maps for each variable.

Table 2 also shows that the soils in the areas B3 and C6 presented high clay contents, conducting more electricity than soils with a sandy particle size. Similarly, Almeida et al. (2006) evaluated these attributes in the region of Campos Gerais (Paraná state) and found that the electrical conductivity measured by a sensor adequately reflected the variation in the clay content of areas under no-tillage.

The maps with occurrence of very high, high, medium, low and very low zones are shown in Figures 3A and 3B.

Figure 4 shows that the visual difference was demonstrated due to the amount of collected data, that is, the soil pH by the Veris sensor had a sampling of 10 readings (samples) per hectare, while one sample

Table 1. Semivariogram parameters for the electrical conductivity (EC; mS m^{-1}), pH and organic matter (OM; %) for the two experimental areas, using the Veris sensor for analyzing the sampling quality.

Area	Variable	Model	Nugget effect (C_0)	Sill ($C1 + C_0$)	Range (a)	DSD ($C1/ C_0 + C1$)	r^2
B3	EC_{30}	Linear	0.840	2.424	272.10	0.75	0.61
	pH	Exponential	0.675	2.236	427.50	0.77	0.71
	OM	Spherical	0.001	0.002	68.98	0.99	0.99
C6	EC_{30}	Exponential	0.001	1.412	73.77	1.00	0.76
	pH	Spherical	0.001	1.575	502.90	1.00	0.97
	OM	Linear	0.003	0.012	547.20	0.80	0.37

DSD: degree of spatial dependence.

Table 2. Average values for the soil attributes observed by the laboratory method (particle size, pH* and organic matter*) and sensor (electrical conductivity - EC, organic matter - OM and pH), and their respective zones.

Area	Zone	EC (mS m^{-1})	Clay	Silt	Sand	pH	pH*	OM	OM*
			%					%	
B3	Very high	8.82	65.3	8.7	26.0	5.8	5.5	2.30	6.5
	High	5.30	58.0	19.0	23.0	5.7	5.3	2.20	6.0
	Medium	4.20	58.0	20.0	22.0	5.9	5.8	2.10	5.5
	Low	3.43	52.0	22.0	23.0	5.7	5.5	2.08	6.1
	Very low	2.31	50.1	27.9	22.0	5.8	5.8	2.00	5.8
C6	Very high	5.57	60.0	29.0	11.0	5.7	5.5	2.40	6.0
	High	4.05	58.0	20.0	22.0	5.7	5.5	2.20	6.1
	Medium	3.59	56.0	23.0	21.0	5.9	6.0	2.10	5.5
	Low	3.24	51.0	38.6	10.4	6.0	6.1	2.00	5.3
	Very low	2.61	44.2	47.9	7.9	6.0	6.1	2.09	6.0

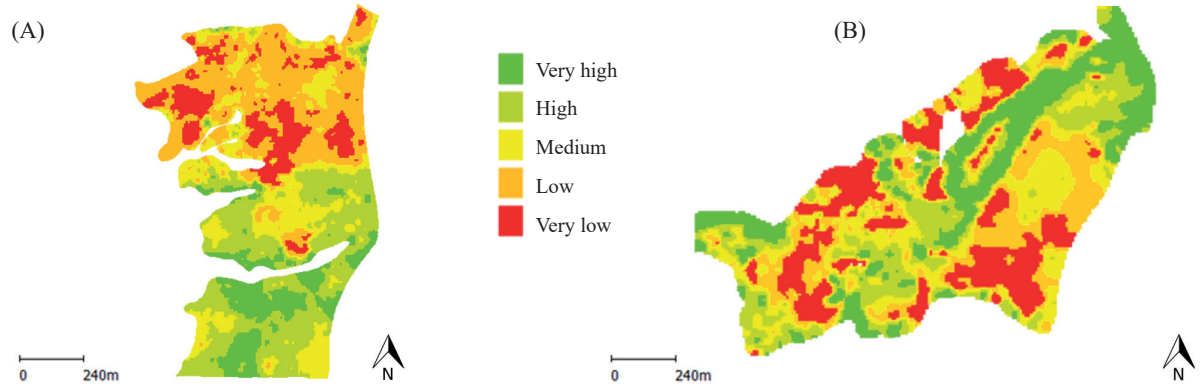

Figure 3. Maps of soil electrical conductivity from the Veris sensor and zones defined in the areas B3 (A) and C6 (B).

was collected every 2 hectares for the laboratory method for the area C6. This difference affects the spatial resolution. The other variables in Figure 5 also presented a higher sampling by the Veris sensor than by the laboratory sampling, thus affecting the spatial resolution.

The classification by zones (Table 3) provided the best fit of the determination coefficients to the data. This is because the zoning provides an average value for each area (5 zones), in a decreasing order of values. Yet, in the grid of points, there is a larger amount of data and also a greater variability, since there is no separation of the average values.

However, this great difference no longer exists when it is divided into zones. In this case, the correlations are mathematically more reliable, and the results are high correlation coefficients to the variables.

Figures 5 to 9 show that all the physical and chemical attributes analyzed in the laboratory had a strong correlation with the electrical conductivity, organic matter and pH values obtained by the Veris sensor, as all the correlation coefficient values were above 0.83.

According to Alves et al. (2013), the electrical conductivity varies as a function of several factors, such as soil water content, clay percentage and type, and ionic concentration in the soil solution. Under similar moisture and salinity conditions, the soil with the highest clay content will have the highest electrical conductivity. Molin & Rabello (2011) evaluated a low-cost equipment for measuring the electrical conductivity, using the Veris sensor as a reference, and also observed that the higher the clay content, the higher is the electrical conductivity value.

Table 3. Correlation between the measured and estimated data of the variables pH and organic matter (OM) of the two areas subjected to two analysis techniques of samples (grid and zone).

Area	Sampling division	pH (r^2)	OM (r^2)
B3	Grid	0.25	0.33
	Zone	0.93	0.69
C6	Grid	0.04	0.63
	Zone	0.96	0.69

Our results corroborate those of Molin & Rabelo (2011) and Alves et al. (2013), in which the clay content was a factor that showed the strongest correlation with electrical conductivity in the two sampled areas. Figure 6C shows a direct relationship between clay content and soil electrical conductivity.

As observed by Faulin (2005) and Molin & Rabello (2011), the correlation coefficients showed dependence among the evaluated soil properties, mainly between electrical conductivity and soil particle size.

The correlation between the pH obtained by the Veris sensor and that by the laboratory analysis was strong (Figures 5A and 7F), showing correlation values of 96 and 98 % for the areas B3 and C6, respectively.

Schirrmann et al. (2011) evaluated the pH values generated by the Veris sensor, relatively to the laboratory data, for soil conditions in Germany, and found a strong correlation. However, Barbosa et al. (2018) obtained opposite results, showing the need for further studies for the sensor calibration to the different soil types found in Brazil, concerning the pH attribute.

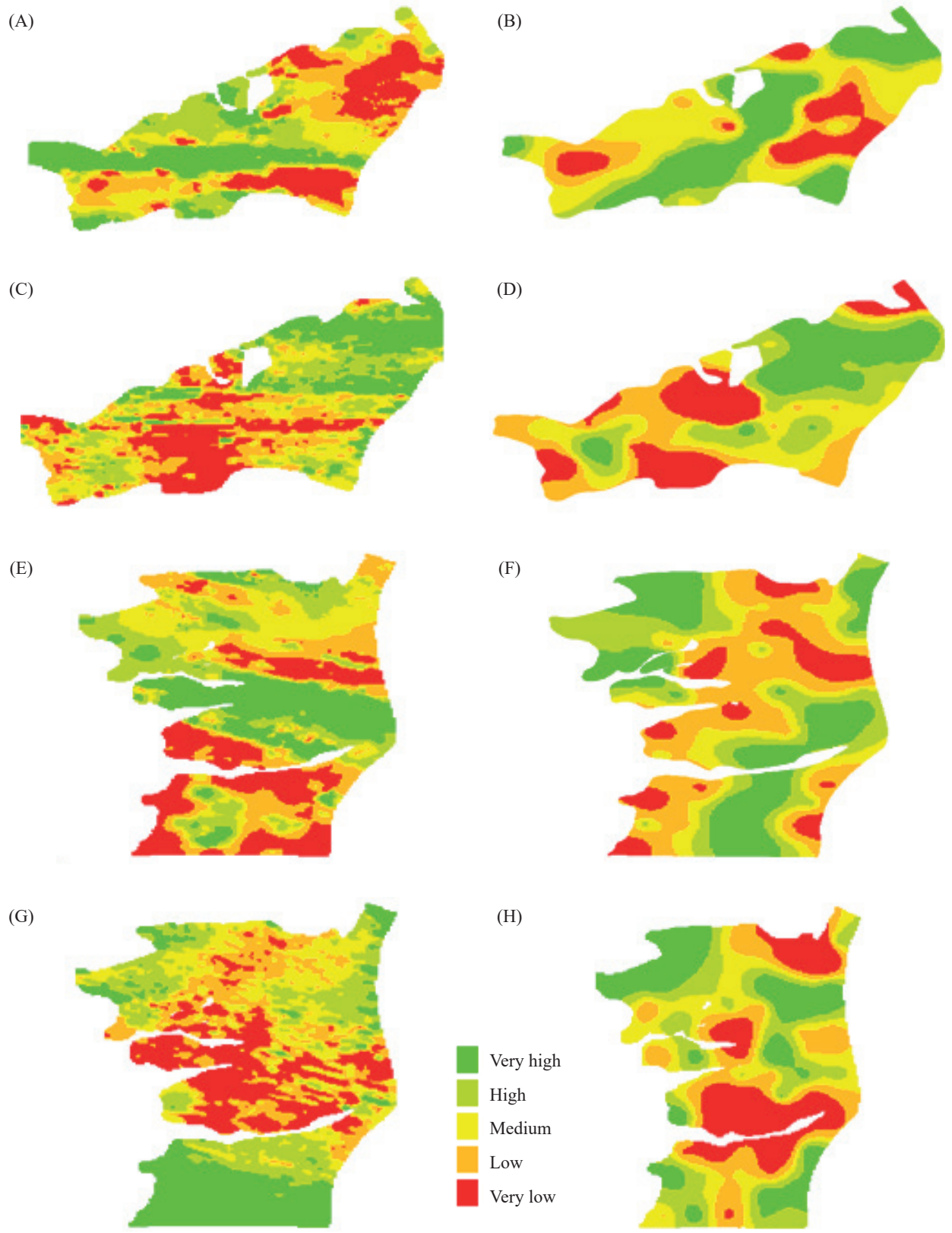

Figure 4. Maps of the studied variables: soil pH by the Veris sensor (area C6) (A), soil pH by the laboratory method (area C6) (B), organic matter by the Veris sensor (area C6) (C), organic matter by the laboratory method (area C6) (D), pH by the Veris sensor (area B3) (E), pH by the laboratory method (area B3) (F), organic matter by the Veris sensor (area B3) (G) and organic matter by the laboratory method (area B3) (H).

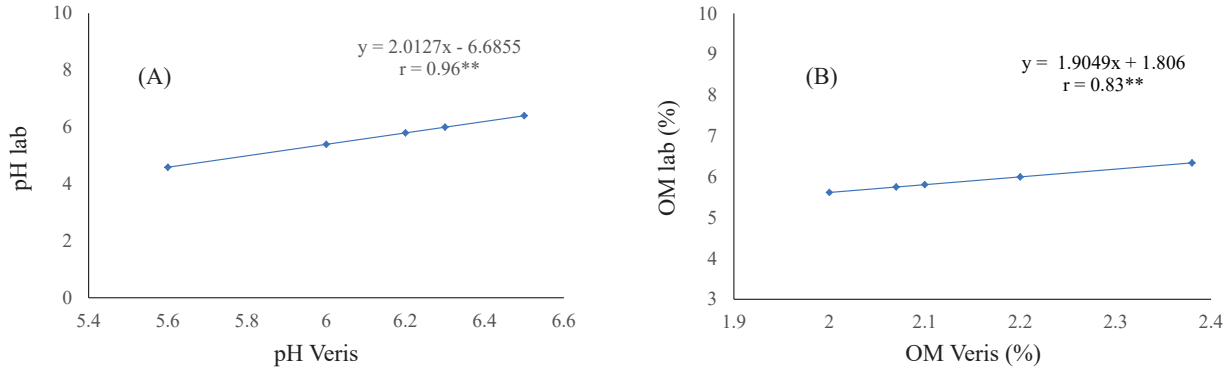

Figure 5. Correlation coefficient (r) between the pH by the Veris sensor and by the laboratory analysis for the area B3 (A), and between the organic matter (OM) by the Veris sensor and by the laboratory analysis for the area B3 (B). ** Significant at 5 %.

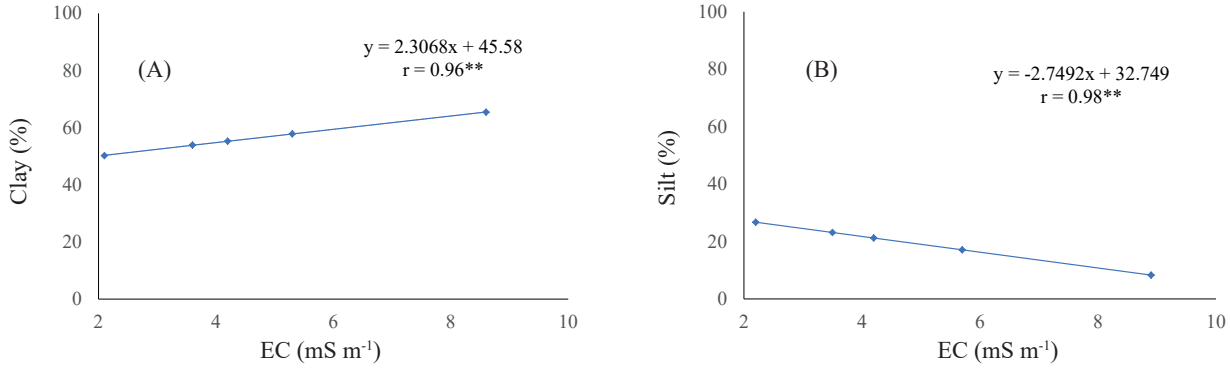

Figure 6. Correlation coefficient (r) between the electrical conductivity (EC) by the Veris sensor and clay by the laboratory analysis for the area B3 (A), and between the electrical conductivity by the Veris sensor and silt by the laboratory analysis for the area B3 (B). ** Significant at 5 %.

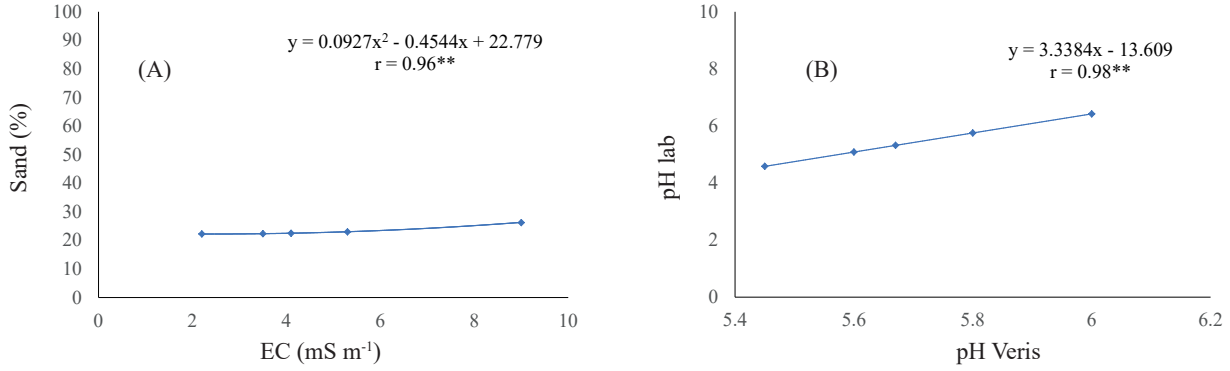

Figure 7. Correlation coefficient (r) between the electrical conductivity (EC) by the Veris sensor and sand by the laboratory analysis for the area B3 (A), and between the pH by the Veris sensor and pH by the laboratory analysis for the area C6 (B). ** Significant at 5 %.

The organic matter showed significant correlation values between the laboratory and sensor data in the two analyzed areas (Figures 5B and 8G), demonstrating that the sensor calibration and the number of samples for the laboratory analysis were balanced and generated strong correlations. Kweon & Maxton (2013) and Brandão et al. (2011) observed the need for a better calibration of pH and organic

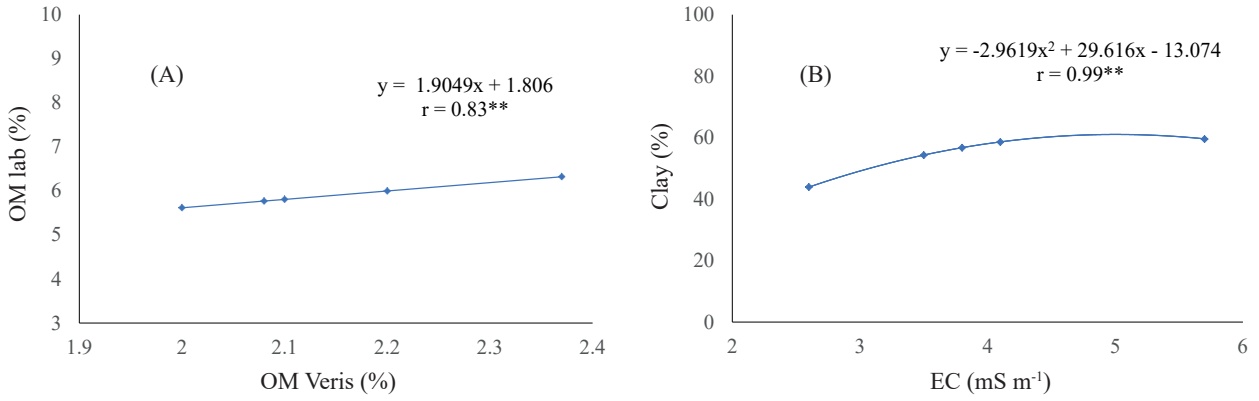

Figure 8. Correlation coefficient (r) between the organic matter (OM) by the Veris sensor and by the laboratory analysis for the area C6 (A), and between the electrical conductivity (EC) by the Veris sensor and clay by the laboratory analysis for the area C6 (B). ** Significant at 5 %.

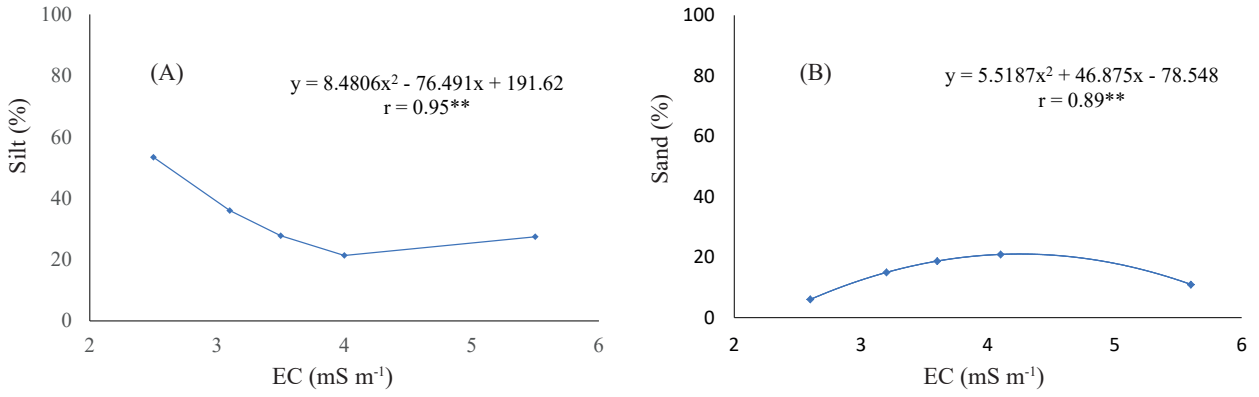

Figure 9. Correlation coefficient (r) between the electrical conductivity (EC) by the Veris sensor and silt by the laboratory analysis (A), and between the electrical conductivity by the Veris sensor and sand by the laboratory analysis for the area C6 (B). ** Significant at 5 %.

matter sensors for different soil types aiming to reduce systematic errors and construct maps more consistent and sensitive to the variability of these attributes in the soil than maps generated from laboratory values.

The coefficient of variation values of the soil attributes (Table 4) are considered low when lower than 10 %, medium from 10 to 20 %, high from 20 to 30 %, and very high above 30 % (Pimentel-Gomes & Garcia 2002). Thus, sand would be the attribute with more problems of interpretation and recommendation, with a coefficient of variation of 30 %.

Differences in results among the laboratories may be explained by the differences in the methodology for determining the soil attributes.

The significant differences found for some attributes among the laboratories did not imply the correlations of the data obtained with the Veris sensor, demonstrating that the sensor may replace the laboratory analysis in areas that already have a good calibration history, when the sensor is well calibrated.

Table 4. Soil attributes and variations of laboratory analysis.

Laboratory	Soil attribute			
	pH	Organic matter (mg d^{-3})	Sand (%)	Clay (%)
IAC	5.6	51	32	55
UFRGS	5.8	47	32	57
FABC	5.9	41	39	54
Codetec	5.6	32	21	57
TecSolo	5.2	42	22	53
CV (%)	17	5	30	5

CONCLUSIONS

1. The soil attributes measured by the Veris sensor may be used for decision-making in agronomic interventions;
2. The electrical conductivity, pH and organic matter data collected by the Veris sensor are reliable and robust, due to the high spatial dependence and correct sampling distance confirmed by the range values;
3. The sensor is a very promising tool, because it presents a high operational capacity and strong correlations between its results and the laboratory data.

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